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METHOD AND APPARATUS FOR PUMPING AND DILUTING A SAMPLE

Field of the Invention

This invention relates to a method and apparatus for pumping a sample to analysis equipment and diluting the sample before it is analysed, or for any other reason.

The invention is described herein with reference to liquid samples which require dilution before they are analysed in a mass spectrometer. However, the invention is not limited to liquid samples or mass spectroscopy and can equally apply to dissolved or suspended samples and any other test or analysis equipment.

Description of the Related Art

Analysis equipment for analysing trace elements in liquids have a limited capability of measuring samples which have relatively high levels of dissolved solid material, or matrix (such as $CaCO_3$ or dissolved salts in water, or the like). The trace elements of interest to the user are often only a few parts per billion, or lower, whilst the matrix can be many parts per million, or higher. Such high levels of matrix can have undesirable effects on the analytical equipment, for example, materials can be deposited on orifices, glassware and ion optical elements. It is, therefore, necessary to dilute the sample prior to analysis.

Inductively coupled plasma mass spectrometers (ICP-MS) typically require a total dissolved solid level of less than 2000mg/l to avoid such deleterious effects. The dissolved solids can become deposited on components within the instrument, for example on the cones which sample the plasma and skim off a portion of the supersonic jet, thus significantly reducing the reliability of the test result

and the results of any other subsequent test. If deposition of materials occurs, the instrument has to be thoroughly cleaned before accurate testing can resume.

Test laboratories are often required to analyse many samples quickly where the matrix content of each sample varies widely. Typically, the user would wish to dilute each sample by a certain amount to determine the analytes present in each sample, and whether the sample can be analysed undiluted. If dilution is required, this initial test provides an indication of the dilution factor necessary to bring the total dissolved solids down to a level tolerated by the instrument.

Such manual intervention is too cumbersome, time consuming and costly if many samples per day require analysis. Presently, samples which introduce too great a loading of dissolved solids for the instrument to cope with are re-analysed once the analyser has been cleaned. Analysis must stop for cleaning, and samples inadvertently analysed after contamination of the analyser must be re-analysed. This requires considerable operator intervention. Such a limit to the throughput of samples is undesirable and operator intervention is costly.

Automated dilution systems have been used previously and, referring to figure 1, such an automated system 10 known in the art is shown in highly schematic form. A sample 12 is drawn from a container by a sample pump 14 to a mixing tube 16. Similarly, a diluent 18 is drawn by a diluent pump 20 to the mixing tube 16 from a separate diluent container. The sample is diluted in the mixing tube where it is completely mixed with diluent. An instrument pump 22 draws the diluted sample from the mixing tube and into the instrument or analyser, not shown in figure 1.

Both the sample and diluent pumps have to be able to maintain accurate flow rates to ensure the sample is diluted precisely. If the dilution is not maintained to a known level and within a relatively tight tolerance, the accuracy of the analysis results may be unacceptable. Likewise, the instrument flow must be maintained at an accurate flow rate to ensure the diluted sample is pumped to the analyser's input at a known, controllable rate. Thus, all the pumps (and their associated flow rates) need to be controlled accurately to maintain accurate test results.

Presently, peristaltic pumps are used to pump the sample, diluent and diluted sample through the dilution system. Typically, dilutions ratios of 50:1 of diluent to sample are used for mass spectroscopy. Hence, the diluent pump rate is typically fifty times greater than the sample pump rate. Peristaltic pumps have a limited range of flow rates and the sample and diluent pumps often operate at the extremes of their flow rate range. Also, the limited flow rate for peristaltic pumps limits the dilution factor by which the sample can be diluted; the maximum dilution occurring whilst the diluent pump operates at a maximum flow rate and the sample pump operates at a minimum flow rate.

The rate at which the diluted sample should enter the instrument (not shown) depends on the type of instrument being used but is relatively low and typically a few millilitres per minute. If this rate is exceeded the instrument will become swamped with diluted sample which will cause problems in the spectrometer and have a detrimental effect on the analysis results. Typically, the combined flow rates of the sample and diluent pumps far exceeds the instrument pump flow rate. This is because all the pumps have relatively similar ranges of flow rates, and

at dilution factors greater than ten, for example, the diluent pump 20 must operate at a high flow rate. This high flow rate typically exceeds the flow accepted by the analysis instrument. It is, therefore, necessary to provide a waste outlet 24 to prevent build up of pressure in the system; excess diluted sample not pumped to the instrument flows to a waste container 26. At high dilution factors, the solution flowing to waste can exceed the flow entering the instrument by a factor of fifty. Materials in the waste container are discarded and, since the high quality diluent necessary for accurate test results is relatively expensive, this wastage is an additional economic burden on test laboratories.

Another automated pumping system 28 known in the art is shown in figure 2 in highly schematic form. Sample 29 is pumped along a first pipe 30 by a syringe pump 31 to fill the syringe (not shown). A valve 32 is closed to prevent fluid entering the syringe from the pump discharge pipe 33. When the pump is charged with an appropriate amount of sample, the valve is opened and the syringe plunger driven at a constant rate to provide a flow of sample along pipe 33 in the general direction indicated by arrow Z. A one way valve in the pump (not shown) prevents the sample from flowing back to the container 29 during the phase when the sample flows along pipe 33.

A mixing region 34 of the pipe is defined by a second pipe 35 adjoining pipe 33 in a generally "T" or "Y" shaped configuration. As solution is aspirated by the instrument pump system (for example, a nebuliser), an uncontrolled pressure drop is produced in pipe 35. This causes an uncontrolled flow of solution along pipe 33' from the mixing region 34. This flow rate is a combination of a controlled

flow of solution from the syringe pump, and an uncontrolled flow of diluent along pipe 35. The inability to control the flow of diluent results in an uncontrolled dilution factor. There is no instrument pump to pump the diluted sample to the analyser in this arrangement.

Problems arise with systems which rely on this arrangement. For instance, there are limits to the dilution factor this system can provide, especially if the analyser requires the diluted sample to be pumped at a specific rate. This problem could be overcome by providing an instrument pump and pressure relief system similar to that shown in figure 1. However, the problems associated with the system in figure 1 now become prevalent with the system, for example, diluent wastage.

Pumping systems known in the art are disclosed in US 4,245,509 (Instrumentation Laboratory Inc.) and US 5,007,297 (Pacific Scientific Company).

Furthermore, contamination of the pump parts exposed to the sample during operation can cause subsequent samples to become contaminated, thus resulting in inaccurate analysis results. This so called "memory effect" problem is particularly troublesome with highly sensitive analysis instruments. As test instruments become more sensitive, this problem further increases. (For example, we have found this problem has very little effect on analysis results when samples are tested using the relatively insensitive atomic absorption analysis instruments, but can be problematic when samples are tested using highly sensitive ICP-MS analysis tools).

Also, certain fluids can damage pump components. Such damaged components can lead to inaccurate flow rates, or

more seriously, render the pump unusable without lengthy repair or regular servicing.

At present, peristaltic pumps are used; the liquid being pumped is only in contact with the tubing in such pumps (which can be made of resilient material). However, peristaltic pumps have inadequate flow rate range and accuracy to dispense a sample solution at a sufficiently low flow rate to avoid discharging qualities of fluid to waste, as previously described. Furthermore, the use of peristaltic pumps limits the dilution factor achievable, because of their limited effective flow rate range.

Summary of The Invention

It is an aim of the present invention to ameliorate the problems associated with the prior art.

More precisely, there is provided a pump apparatus for pumping a sample to an analyser for analysis, comprising; a first pump arranged to pump the sample into a buffer region at a first flow rate, and a second pump arranged subsequently to pump a second fluid into said buffer region at a second flow rate to cause at least a portion of the sample to be displaced from the buffer region to the analyser, said second pump being operable so that the second flow rate is more accurately controllable than the first flow rate.

Advantageously, the second pump means for pumping the second fluid into the buffer region is isolated from the sample such that it does not come into contact with the sample and therefore overcomes the memory effect problem. Furthermore, because the second pump's flow rate can be controlled with a relatively high degree of accuracy, subsequent dilution of the sample is achievable to higher

levels and which have less effect on analysis results than with prior art systems, and which we have found are necessary for relatively accurate analysis equipment, such as ICP-MS for example.

Embodiments of the invention may also comprise a flow switching means moveable between a first and second position, the flow switching means being so arranged that;(a) when the switching means is in the first position, the buffer region is in fluid communication with the second pump, and (b) when the switching means is in the second position, a first buffer region port is in communication with the outlet conduit, and a second buffer region port is in fluid communication with the first pump.

Embodiments of the invention can also comprise a waste conduit so arranged that, when the switching means is in the first position, the buffer region is also in fluid communication with the waste conduit.

Embodiments of the invention may also comprise, when the switching means is in the second position, the waste conduit is in fluid communication with the second pump, the second pump can be being arranged to pump a flush agent.

Embodiments of the invention can further comprise,

when the switching means is in the first position, the first pump is in fluid communication with the outlet conduit, so that the second fluid can be pumped into the outlet conduit for displacement of the sample fluid or second fluid therein.

Advantageously, embodiments further include a mixing region for mixing the sample with a diluting agent, and a third pump means for pumping diluted sample from the mixing region to the analyser, wherein, the mixing region is disposed between the outlet pipe and the analyser.

There is further provided a method for pumping a sample fluid for analysis to an analysis instrument using a pumping system comprising, a buffer region for storing the sample fluid, the buffer region being arranged with at least two ports, the method comprising, pumping a second fluid into the sample fluid buffer region through a first port, using a first pump means, thereby displacing the sample fluid therein to the analyser.

Advantageously, when the system further comprises a second pump means, and an outlet conduit arranged for flow of the sample fluid and/or fluid to the analyser, the method may also comprise pumping the sample into the buffer region using the second pump means.

Advantageously, when the system further comprises a flow switching means moveable between a first and second position so arranged that; (a) when the switching means is in the first position, the buffer region is in fluid communication with the second pump, and (b) when the switching means is in the second position, a first buffer region port is in communication with the outlet conduit, and a second buffer region port is in fluid communication with the first pump; the method further provides, pumping the sample into the buffer when the flow switching means is in the first position using the second pump, switching the flow switching means to the second position, and pumping the second fluid into the buffer region using the first pump for displacement of the sample therein.

The invention yet further provides a method of preventing contamination of a first pump means with a sample, the method comprising; disposing the sample in an intermediary region using a second pump, displacing the sample from the intermediary region by pumping a second

fluid into said intermediary region using the first pump means.

A main advantage of the present invention broadly reside in a pumping or dilution system in which the sample is pumped to the analysis instrument at a flow rate determined by a highly accurate pump, without exposing that pump to the sample. This can reduce the likelihood of the pump becoming damaged or contaminated by the sample. Also, the accurate flow rate may be required for relatively high precision dilution of the sample.

Embodiments of the present invention also have the advantage of providing a pump/dilution system and method which is more easily controlled and to better accuracy levels of flow rate and dilution factor. Also, virtually no diluent is wasted during normal operation. A controller can advantageously be used to control the second and third pump flow rates. A dilution factor equal to the ratio of fourth to second flow rates can easily be controlled by adjusting the second and/or third pump flow rates accordingly. Control of the dilution factor can occur in substantially real time in response to data from the analysis equipment. Also, the components of the pump used to provide accurate, low level flow of the sample are not exposed to potentially damaging corrosive, chemical attack, or wear caused by suspended solids in the sample. Sample solution does not enter the second pump.

Embodiments of the invention have further advantages of substantially reducing the operator intervention, and increase the sample throughput rate. The embodiments aim to provide automated dilution of the sample at a consistent and safe level before the sample is introduced into the analyser. The rate of sample throughput can be

substantially increased. Dilution of the sample to a safe level also has the advantage of allowing the required precision of analysis to be carried out on trace levels within the sample by automatic dilution of the sample. The sample throughput can also be increased by a relatively rapid introduction of new (or different) sample solutions up to the buffer by controlling the flow rate of the sample uptake. The cost of diluting samples can be reduced by reducing the amount of diluent used by the dilution system; only the volume of diluent required to dilute the sample to a required safe level can be consumed and little or no diluent is wasted. By 'safe level', we mean a dilution factor necessary to avoid contamination of the analysis instrumentation.

Detailed Description of An Embodiment

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of a pump system known in the art and described above;

Figure 2 is a schematic diagram of a pump system known in the art and described above;

Figure 3 is a schematic diagram of a pump system embodying the present invention with a switch in a first position; and

Figure 4 is a schematic diagram of the switch of figure 3 shown in a second position.

Referring to Figure 3, a pump system 50 embodying the present invention is shown in schematic form. A sample 52 to be analysed is drawn from a container by an automatic sampler 54 along a first, or sample uptake pipe 56 to a

valve, or pipe flow switch 58. The automatic sampler used in this embodiment is well known in the art and comprises a pump (not shown) and a probe 60. The probe is moveable to be inserted into a fluid in a container placed underneath the probe. Different containers can be placed on a carrousel (not shown) so that different samples or a washing agent 62 can be drawn into the pump system via the probe and automatic sampler pump.

The switch 58 comprises six input/output ports, A, B, C, D, E and F, and three internal pipes or conduits which each join one port with another. The switch is movable between two positions so that the flow of fluid from one pipe to another pipe can be switched from that pipe to a different pipe when the switch is moved. The switch is shown in a first position in figure 3 and a second position in figure 4.

In an initial, or sample uptake phase, whilst the sample is being drawn in to the system, the switch is configured as shown in figure 3 (first position), so that port A is connected to F, B is connected to C, and D is connected to E. Thus, fluid can flow between pipes connected to ports A and F, B and C, and D and E respectively.

A second, or sample storage pipe 64 connects port E with port B. Thus, in the sample uptake phase, the sample is pumped through the switch port D, out the switch port E and into the second pipe 64; the ports act to allow fluid to flow through the port and into or out of a pipe, conduit or chamber attached to the port. Any fluid already in the second pipe is displaced by the sample entering the second pipe into the switch via port B. A third, or waste pipe 66 is connected to port C of the switch (which is, in turn, connected to port B in the sample uptake phase) and a waste

unit 68. Thus, fluid displaced from the second pipe is pushed through the switch (via ports B and C), along the third pipe to a drain, or waste unit.

The second pipe 64 has sufficient volume to contain or store enough sample fluid required for testing. Typically, for ICP-MS applications, a volume of 1-10 ml is required for a single sample to obtain sufficient analysis results, although this volume depends on a dilution factor of the sample entering the mass spectrometer. The automatic sampler is controlled to draw a volume of sample into the second pipe from the sample container which exceeds the combined volume of the pipe 56, the second pipe 64 and any volume occupied by fluid with the switch 58. This ensures the sample completely fills the second pipe. Thus, any fluid within the second pipe, prior to the sample being drawn into the pipe, is flushed out of the second pipe 64. Also, the interface between the sample and any fluid which occupied the second pipe prior to sample uptake is now in the third pipe 66 when the sample update is complete.

A second, sample pump phase of the pump system shall now be described in which the sample is pumped to the instrument for analysis. Once the second pipe 64 has been filled with sufficient sample, the automatic sampler stops pumping sample from the container. The switch is switched to the second position shown in figure 4, where Port A is connected to B, C to D, and E to F. This switch configuration now connects a fourth, or system pump pipe 70 to an end on the second pipe, via switch ports A and B. The end of the second pipe connected to port B is distal from the automatic sampler, and is the end through which fluid in that pipe passes to the waste outlet (as previously

described). Thus, this end contains sample fluid, since all of the second pipe has been filed with sample.

A first, system pump 72 is now operated to pump a fluid, or diluent 73 from a container 74 into port A. Preferably, this fluid is suitable for diluting the sample and should have an extremely high level purity. The fluid is pumped into the switch (port A), and thence into the distal end of the second pipe (port B) by pump 72. In this way, the sample in the second pipe 64 is displaced from the second pipe, through switch port E, out of switch port F and into a fifth, or switch outlet pipe 76. The rate of flow (litres per minute) along the fifth pipe is equal to the rate of flow of pump fluid along the fourth pipe 70. Of course, this assumes the fluids are incompressible and that the pipes do not expand during normal operations.

The sampler probe is, at the same time, now switched so that another fluid 62 can be pumped into pipe 56, through switch 58 and along the second pipe 66, via ports D,E,B and C. Preferably, the another fluid is suitable to wash, or flush out sample fluid in pipe 56 and the probe thereby cleaning these components in readiness for the next sample by flushing sample solution to the waste container 68 through pipe 66. The first pipe is now in communication with the third pipe 66, via switch ports D and C (since the switch is in the second position), so that the wash fluid flushes sample from pipe 56 and into waste pipe 66 to the waste disposal 68.

The flow rate of the sample passing along the fifth pipe 76 is governed by the sample pump 72 to Flow 1. The sample enters a mixing region 78 at the end of fifth pipe where it is mixed with a diluent 80. At the mixing region 78, the fifth pipe 76 is joined to a sixth, or sample

diluent pipe 82 to form a single, seventh, or instrument input pipe 84. This mixer is a "Y" or "T" configured junction in the tubing or pipes. A more complex shape or configuration could also be used to encourage mixing of sample and diluent solutions. The exit of the mixing region comprises a single pipe 84 disposed between the mixing region and a second pump 86 which pumps fluid from the mixing section to an instrument (not shown) for analysis.

Mixing of the sample and diluent to form a diluted sample takes place at the interface of the fifth, sixth and seventh pipes 76, 82 and 84 respectively. Additional mixing may also occur for some length along the seventh pipe from the mixer to the analyser (not shown) but mixing should be complete before the diluted sample enters the analyser. Mixing occurs as a function of the turbulent flow of the sample and diluent at the junction and along the fifth pipe, and also by diffusion of the two fluids. In this embodiment, mixing may also occur as the fluid passes through the second pump 86.

The first, or sample pump 72 is preferably a piston type pump, similar to the milliGAT pump head supplied by Global FIA Inc. (disclosed in US6,079,313). This type of pump allows a much greater range of flow rates, compared to peristaltic pumps, for instance, and can operate to continuously pump relatively small volumes of sample at a constant, or varying flow rate, as desired. In particular, it is capable of delivering very low flow rates at high levels of accuracy and precision. Furthermore, this piston pump system does not suffer the disadvantages associated with the prior art pump systems described previously. The second, or instrument pump may be the same type as the first pump, or, if appropriate, may be a peristaltic pump.

Typically, the automatic sampler pump is also a peristaltic pump. The use of such a pump for sample pumping has the advantage of the sample remaining in the pump tubing and thus, the sample does not damage any pump components. However, peristaltic pumps can not dispense fluid at low volume rates (typically micro-litres per minute), at the precision required and with near pulse-less delivery. Peristaltic pumps are therefore limited to relatively high volume flow rates (millilitres per minute) and at relatively inaccurate and imprecise pumping rates. Such peristaltic pumps are suitable for the application described herein where the sample store can be filled rapidly and the pumps do not suffer corrosion or mechanical damage. Of course, such pumps are not suitable for pumping the sample to the mixer 78 because they do not have the same amount of controllability in consistent flow rates which are required to maintain accurate dilution factors of the sample. In other words, the flow rate of these unsuitable pumps varies, or pulses to an extent which can be detrimental to the consistency of the diluted sample.

The diluent 80 is drawn from a diluent container container 81, up the sixth pipe 82 to the mixing section 78 where it mixes with the sample, and hence dilutes the sample. The end of the sixth pipe at which the diluent enters the system is completely submersed in the diluent to ensure air does not enter the system. The flow from the mixer to the instrument of the diluted sample is accurately controlled by the second pump 86 at Flow 3. Thus, when Flow 1 < Flow 3, the diluent is drawn along the sixth pipe 82 to the mixer at a flow rate Flow 2, following the equation

$$Flow\ 1 + Flow\ 2 = Flow\ 3 \quad ;$$

assuming the liquids in the pipes are non-compressible. (The flow can be measured in litres per minute).

Preferably, Flow 3 is kept constant by the second pump 86, hence the rate of arrival of diluted sample of the instrument is constant. Varying the flow rate of the first pump therefore changes the dilution factor *D* by which the sample is diluted, where

$$D = Flow\ 2 \ / \ Flow\ 1 \quad ,\text{or}$$
$$D = (Flow\ 3 \ / \ Flow\ 1) - 1.$$

So, from the equations above and assuming Flow 3 is constant, a decrease in the first pump's flow rate (*Flow 1*) increases the diluent flow to the mixer section, and hence increases the dilution factor *D*.

An example of how the pump system embodying the invention can operate with an ICP-MS instrument is now provided. During operation, all samples are routinely diluted by a discrete dilution factor D_1 before the sample is analysed. D_1 is initially set to a relatively high level so that the sample is diluted to such an extent that any dissolved solids (or matrix)in the sample are sufficiently diluted when the sample is analysed. In this way, adverse effects to the analysis instrumentation or the test result can be prevented or reduced. Typically, $D_1 = 100$.

Analysis software which checks the analyser results determines the extent of diluted matrix in the sample, to see whether further dilution is necessary. Also, the analysis results are processed to determine the precision of the measured analyte signal. For instance, if the analyte signal is too weak, the dilution factor may need to be

reduced. Moreover, the instrument may not be able to measure analyte concentration with the required accuracy if the analyte signal is too intense (in which case the sample may require further dilution by a factor D_2).

D_2 can be calculated by comparing the matrix signal from the analyser with a pre-determined maximum level used for providing adequately accurate results. As previously described, the new dilution factor D_2 is achieved by adjusting Flow 1 of the first pump 72. As a result, the dilution factor can be controlled in real time as analysis results are made available from the analyser.

The flow rates of the first and second pumps, 72 and 86 respectively, are controlled by a controller or PC 88. Data from the instrument analysis results are inputted to the controller along link 100. The first and second pumps are controlled via links 102 and 104 respectively. The automatic sampler can be controlled along link 106 and the switch is controlled along link 108. Flow rate information or data can be passed from the pumps (or any flow meters - not shown) back to the controller for use by the controller. Therefore, it is possible for the controller to change the dilution factor (if necessary) having regard for the analyser results. For example, if the results show too much matrix remains in the diluted sample for accurate analysis, the controller can reduce the first pump's flow rate, thereby increasing the dilution factor, as described previously.

Once the sample has been analysed and the required results obtained, the system 50 can start the dilution process for a new sample, as follows. The controller stops the first and second pump 72 and 86 and the switch is moved into the initial configuration (described above). Pumps 72

and 86 are re-started and the first pump 72 then starts to pump diluent into the fifth pipe 76 via switch ports A and F, and fourth pipe 70 at a slow rate substantially less than Flow 3. With the instrument pump 86 running at, or close to Flow 3, a large amount of diluent is thus drawn from container 81 and the sample is diluted to a high dilution factor and pump into the analyser instrument. The analyser continues to operate without taking any readings. First pump 72 finishes pumping diluent when all the sample in the fifth pipe 76 is displaced from therein. This can be controlled by pumping the second fluid or diluent 73 at a predetermined flow rate F, for a predetermined time T, where,

$$T > V/F$$

and V is the volume occupied by the fluid in the switch (between ports A and F) and the fifth pipe 76. This helps to ensure all the sample remaining in the fifth pipe is flushed out and does not contaminate the next sample for analysis. T can be minimised by reducing the length (and hence volume) of the fifth pipe between the switch and the mixing region.

At the same time, a new sample is drawn into the system by the automatic sampler 54, the first and second pipes (56 and 64) having been flushed of any sample as previously described.

During the second or sample pump phase (the valve 58 having been switched to the second position), the first pump 72 operates at substantially Flow 3 for an initial period and until all the diluent 73 in fifth pipe 76 is displaced by sample fluid from the second pipe 64. When the fifth pipe is completely full of sample, the first pump's flow rate is reduced to Flow 1 and so dilution of the sample takes place,

as described above. The time needed to completely fill the fifth pipe with sample can be calculated using the appropriate equation.

In this way, the sample is pumped to the instrument at an accurate flow rate required for accurate dilution and without the sample contaminating or corroding the first pump's 72 components. Furthermore, contamination of the system components is greatly reduced with the flush cycle employed in the present invention.

An alternative method of determining the dilution factor can include "spiking" or "lacing" the sample solution with a known substance at a known concentration level. The spike is often referred to as an Internal Standard. Analysis of the analyser's results shows how much the sample has been diluted by the reduction of the level of known substance in the results. Of course, the known substances should be one which is not present in the sample or diluent before the spike is added. Such known substances might include Rhodium or Indium, for example.

To obtain very accurate dilution factor levels it is preferable to spike both the sample and the diluent. For example, the sample can be spiked with 100 parts per billion (ppb) concentration levels of Rhodium and 10 ppb of Indium. The diluent is not spiked with Rhodium, but is spiked with indium at a concentration level of 10ppb. If the sample is diluted by, say, a factor of fifty, the Rhodium concentration is 2ppb (after dilution). The Indium internal standard is still at a concentration level of 10 ppb as both the sample and diluent contain 10 ppb of indium.

However, the value of Rhodium concentration varies if there is an instability in the dilution (such instability might be caused by an air bubble in the mixer, or by

inconsistent mixing of sample with the diluent, for example). In the case of an air bubble passing through the system, the Rhodium concentration levels might read 1.2 ppb, followed by 1.99 ppb on the next batch and 2.0 ppb on the last batch. This leads to a mean value of 1.73 ppb, or a 13.5% error of the expected dilution factor of 50:1. A correction for each batch can be made by scaling the values for each batch; the scaling factor for the first batch would be 2/1.2, the scaling factor for the second batch would be 2/1.99 and the scaling factor for the third batch would be 2/2.0. This can eliminate any errors in perceived concentration levels of the sample, which would otherwise be in error had the anomaly in the dilation factor not been noticed. This spiking, or use of an internal standard, allows for dilutions for in excess of 50:1 without the risk of micro-bubbles or mixing effects causing errors in data.

Furthermore, spiking the diluent and sample with Indium having the same levels of concentration is advantageous, particularly in a situation where the sample is pumped to the mixer and fluid in the mixer is pumped to the instrument, but diluent is not actively pumped to the mixer (i.e., there is no pump on the line between the diluent vessel and the mixer, so the flow of diluent is related to the relative flows of the sample pump and instrument pump). Problems can arise when a zero dilution factor is required. To achieve zero dilution, both the instrument and sample pumps should run with the same flow rates. However, if the sample pump is running slightly faster than instrument pump, then a portion of the sample is forced into the diluent, contaminating the diluent. It is therefore preferable to run the sample pump with a flow rate of the order of 10% less than the instrument pump's flow rate. This way the

sample is only slightly diluted. Detecting the concentration levels of Rhodium can account for, or determine this small dilution factor.

The indium spike can also be used to detect and/or determine any variations which might occur in the sample ionisation process. In the case of ICP-MS the ionisation occurs in a plasma torch, and variations in the torch's consistency or plasma condition can be detected by the levels of indium detected in the mass spectrum. This is so because indium concentration levels should always be 10ppb, but if less than this concentration is detected then a correction can be made to factor into the result inconsistencies in ion formation, for instance.

The throughput of an instrument embodying the present invention can be greatly improved and less intervention from a human operator is required. Furthermore, if the dilution factor is maintained at a relatively high level, the inlet of the analyser can be prevented from becoming contaminated with matrix materials, thus reducing the downtime necessary for cleaning the instrument.

The pump system described above are in a 'closed' configuration, by which we mean the sample and diluent are contained in the system from the switch to the output. By keeping the system closed the equations above are maintained during operation. It is therefore important to make sure the diluent and the sample do not run out during operation to prevent air entering the system.

The tubing or pipe components of the pump system 50 should be made of suitably rigid materials to prevent expansion or contraction under any pressure. Such expansion or contraction is undesirable since it affects the volume occupied by the sample, diluent and diluted sample. The

expansion and contraction can be tolerated if their extent is determinable or predictable.

The mixer should preferably be designed to ensure full mixing of the sample and diluent by creating a turbulent flow in the mixing region of the pipe.

The first and second pumps should provide a substantially continuous flow, without any pulsing. The flow rate from each pump can be determined by using independent flow meters disposed fore or aft of the respective pump, with an appropriate feedback loop to the pump controller. Alternatively, the dilution factor can be measured by the use of an internal standard. An appropriate software programme can be used by the controller to automate the dilution of the samples and change-over from one sample to the next, as described above. The controller might comprise a desktop PC with appropriate input and output devices to monitor and control the pumps and flow switching device 58, using an appropriate software programme.

Examples of samples used by embodiments of the present invention include drinking water, waste water, sea water, diluted acids, urine, blood, spinal fluid, dissolved solid or gaseous samples, or the like. These examples are by no means exclusive, and any liquid sample which requires analysis can be diluted prior to entering the analyser by pumps which embody the present invention. Of course, an appropriate diluent is required for different samples and the choice of diluent for a given sample does not form part of the present invention. The diluent may be de-ionised water, ethanol or the like, but whatever is most suitable depending on the sample being analysed.

The embodiments described above provide a apparatus and method for pumping a sample into a store or buffer,

relatively quickly and using an inaccurate, non-uniform flow rate pump (which is generally inexpensive). The sample is then removed or dispensed from the store using an accurate pump, at relatively slow volumeric flow rates (if required) and such that the sample does not enter the accurate pump or contaminate the pump's components. In this way, cross-contamination of samples or pump corrosion can be avoided.

Further embodiments of the present invention will be envisaged by the skilled person, without leaving the scope of the claims. For example, the embodiments have been described using in-line pumps, but it may be desirable to use other pumping systems. Also, diluent 80 and 73 can be contained in the same container. Furthermore, the wash solution in container 62 may also comprise diluent in a common container with 80 and 73.